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Concatenation occurs one morpheme at a time: Infixation in Choctaw

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Abstract. In this paper we show that phonological spellout must occur one morpheme at a time, and in an order that is sensitive to hierarchical structure, rather than the linear order of morphemes present in the surface form. We argue that this sensitivity to hierarchical structure reflects the absence of a phase-wide linearization step in phonological derivation. Instead, the phonological content of each morpheme is concatenated to the linear stem and the full form is computed for each morpheme, moving up the morphosyntactic tree. We base our arguments on verb forms with two different aspectual infixes in Choctaw (Muskogean), which exhibit interwoven interactions between phonological and morphological processes, making it possible to identify the necessary order of concatenation and derivation steps in order to generate correct phonological forms.

Keywords. phonology, syntax-phonology interface, infixation, prosodic structure, morphology, Choctaw, Muskogean

1. Introduction: The timing of the transfer between morphosyntax and phonology is a crucial issue for all theories of the interface, especially those that propose a (quasi-) modular relationship between these units, where the amount of interactive exchange of information between morphosyntax and phonology is limited. For example, Lexical Phonology and Morphology (Kiparsky, 1982), phonology takes place cyclically, after each morpheme is added – that is: phonology applies often and locally. At a slightly larger level, Prosodic Morphology (Selkirk, 1978 and following work) proposes that phonology applies within prosodic constituents, from phonological words and phrases all the way up to intonational phrases; (see Sato, 2009 for a more recent application of this concept). Some phase-based approaches to morophosyntax (see Chomsky, 2000 and following work) propose that phonology is computed after the SynSem structures are spelled out at a phase boundary (eg. vP and CP). This may correspond to prosodic chunks, or it may not. At a much larger scale, classic Optimality-Theoretic approaches to the architecture of the grammar are global – here, phonology is computed only at the very end of the derivation, so there is no smaller "chunking", though constraints may refer to prosodic and/or syntactic boundaries. (see McCarthy, & Prince, 2001; Wolf, 2008). This debate is long-standing and heavily contested (in addition to the above, see Chomsky et al. 1956, Pesetsky 1979, Kiparsky 1982, Halle & Vergnaud 1987, Kiparsky 2000 Chomsky 2008, Newell, 2015 and others cited within).

We can adjudicate between these approaches by looking at a highly agglutinative language where several sets of morphological and phonological rules interact. By deducing the ordering of these operations, we can infer which morphological additions are visible to which phonological processes. In this paper, we show that Choctaw (Muskogean, US) is an excellent case study for this. We demonstrate that the way morphological and phonological processes interact in Choctaw is compatible only with frameworks in which phonology applies repeatedly and locally.

In the next section, we give a brief overview of the theoretical background from which we approach this topic, including our assumptions about the structural syntax and morphology of Choctaw and the architecture of the grammar overall. In Section 3, we show that the order of

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operations in Choctaw is not consistent with a globalist approach to the phonology-morphology interface –morphology and phonology must be built incrementally. In Section 4, we use phonological evidence investigate the order in which the morphological derivation takes place; we show that the Choctaw facts are consistent with a derivation that proceeds from the bottom of the syntactic tree upwards, not left-to right. That is, the order of the morphological derivation is sensitive to hierarchical, not linear order. In section 5, we summarize our findings and conclude.

2. Theoretical Background

2.1. DISTRIBUTED MORPHOLOGY: In this paper, we take an approach to morphosyntax which is consistent with work in the Minimalist Program (Chomsky, 2000) and Distributed Morphology (Halle & Marantz, 1993 and following work). As in Distributed Morphology, we assume that affixes are syntactic heads that do not differ fundamentally from word-level heads in their representation or arrangement relative to other heads. This framework is especially useful for an agglutinative language like Choctaw, as units of meaning which may be expressed as full words in other languages (like tense/aspect marking and complementizers) are morphemes in Choctaw.

In this framework, abstract semantic and syntactic features are built up through a series of "Merge" operations to make a hierarchical structure of syntactic terminals, which are "shipped off" (often in chunks, or "phases") to morpho-phonology to be converted into a phonological string. The output of the syntax consists of lexical roots, syntactic and semantic features, and the hierarchical relationships between them. Spellout, which is discussed in the next section, is the process by which these are linearized and realized phonologically.

One's theory of the interface is mostly independent from the theory of morphosyntax, so even under a Distributed Morphology approach to the structural properties of sentences and words, this "shipping off" process can happen by morpheme, by word, by syntactic phrase, by phase, or globally: the aim of this paper is to separate between these hypotheses about the nature of the interface. The semi-independence of assumptions about morphosyntax and spellout also means that our findings may coexist with quite different assumptions about morphosyntax, e.g. phrase structure rules or finite-state grammars.[1] We use Distributed Morphology mainly as a consistent vocabulary with which to formalize our findings; these findings are not dependent on that theory.

2.2. STEPS OF SPELLOUT: We conceptualize Spellout as consisting of the following steps.

Firstly, the content of each syntactic terminal (roots and features) *is replaced with phonological content*. We represent this step as Vocabulary Insertion rules, which take roots and features as inputs and give phonological forms as outputs. For example, the Vocabulary Insertion rule in (1a) means that the root "witch" is realized as /wɪtʃ/; (1b) means "the feature [plural] is realized as [əs] after the root is "bush" or "witch", [ən] after "ox" or "child" or [s] elsewhere. Like the syntactic assembly, Vocabulary Insertion occurs one morpheme at a time, starting at the bottom of the syntactic derivation and moving upwards (this is argued very convincingly in Bobaljik, 2000).

[1] One exception to this is paradigmatic approaches to morphology, in which the word isn't "derived" from morphemes in the same way, so there cannot meaningfully be a point within the derivation at which a phonological process occurs. As assuming that whole words are the atomic units of syntax forces phonological processes to happen higher than the word level, we believe that the data in this paper poses problems for paradigmatic theories, but we do not discuss this further.

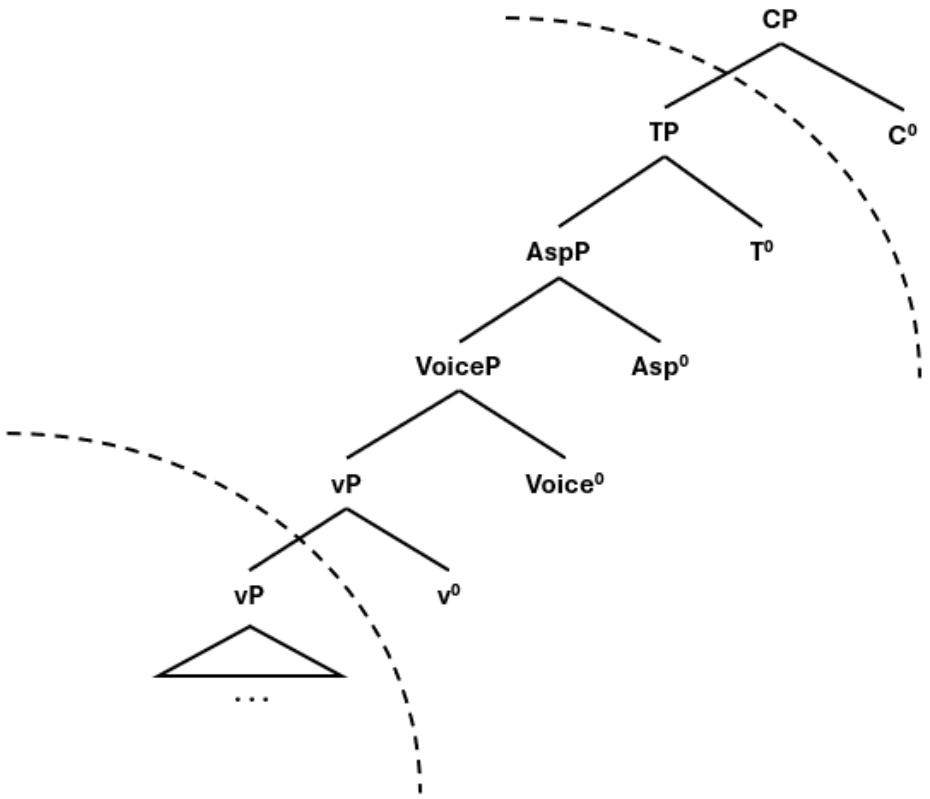
(1) a) √WITCH -> /wɪtʃ/
b) [+plural] -> /əs/ / (√WITCH, √BUSH etc....) _
-> /ən/ / (√CHILD, √OX etc....) _
-> /s/ / elsewhere

Secondly, the structure is *linearized* – the terminals lose their hierarchical structure and are organized as a string. We assume that the location of each morpheme is specified in its lexical entry (e.g. it is specified within the English plural morpheme that it is located to the right of the root), though this isn't a crucial part of the analysis.

Finally, *phonology* takes place; this is usually conceptualized as a separate step after Spellout. This step does not have access to any hierarchical information or synsem features – it is only sensitive to the phonological forms of the stems. This may take the form of ordered rules (Chomsky & Halle, 1968) or constraint-based computation (McCarthy & Prince, 2001).

Throughout the article, we compare the Choctaw data with predictions made by a "phase-based" approach to morphosyntax. By "phase-based", we mean versions of the interface where there are specific points in the syntactic tree (either intrinsically or extrinsically defined) at which all of the morphosyntacic features up to that point are spelled out, such that there is some degree of "invisibility" between morphological features spelled out in different phases. There is some diversity within phase-based approaches on what constitutes a phase boundary, and the degree of transparency at phase edges (Boeckx & Grohmann, 2007; Bošković, 2014; Richards, 2011). For consistency, we refer to the original proposal of phases as given in Chomsky (2001), where phase boundaries are *vP* and *CP***.** Therefore, we assume a structure of the syntactic spine of Choctaw as shown in (2); the 'phase-based account' that we compare our proposal to has phase boundaries represented by dotted lines.

(2)



The crucial question of this paper is: does this phase-based model make the correct predictions about interactions between morphology and phonology in Choctaw? In the remaining sections we argue that *no*- the Choctaw data requires Spellout to happen at more granular intervals than vP and CP.

3. Spellout by derivational step

3.1. CHOCTAW MORPHOLOGY: The first case study in this paper looks at tense and aspect markers in Choctaw. Choctaw, like all Muskogean languages, features a set of infixes that contribute aspectual meaning to verbs. Other than the g-grade (which will be discussed in Section 4), aspect markers appear after the penultimate vowel of the verb stem, but before any coda consonants of the penultimate syllable.

(3)	(a)	halalli	(b)	halá**n**lli[2]
		halat-li		halat-li**-n-**
		grab-TRANS		grab-TRANS-DUR-
		'grab'		'hold'

This is an infixation site is difficult to capture formally (Samuels, 2009). However, for our pur-poses it is sufficient to know that the infixation location is always the same for a given aspect marker, regardless of the length or shape of that stem.

(4) Durative marking on verbs of different shapes

(a) pí<n>.sa	'seeing'
(b) bá<n>sh.li	'cutting'
(c) wa.shó<n>.ha	'playing'
(d) ha.lá<n>l.li	'holding'

[2] Choctaw does not show a contrast between long, nasalized vowels and /Vn/ sequences. Following Katenkamp (2021) we treat the n-grade/durative aspect morpheme as an infixed /n/ rather than a [nasal] feature despite the fact that the form in (3.b) will typically be pronounced [halá̰:lli]. This differs from other literature (e.g. Broadwell, 2006) that treats nasality as a vowel contrast and represents it with a macron below the vowel, e.g. <a̲>.

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(In existing Muskogean literature, these infixes are called 'grades' and each has a conventional name (see Nicklas, 1972, Ulrich, 1986, Willmond and Munro, 1994 for examples). Each 'grade' in Choctaw is presented below, with its conventional name, approximate semantics, and an example.

(5) Choctaw aspect markers

zero-grade	neutral	pi.sa mo.ma	'see' 'be all'
n-grade	durative	pí<n>.sa mó<m>.ma	'look' 'still'
hn-grade	iterative	pi.<hín>.sa	'look (repeatedly)'
y-grade	terminative	pí<y.yii>.sa mó<y.yoo>.ma	'(finally) see' 'all (emphatic)'
h-grade	resultative	pi<h>.sa	'notice'
g-grade	delayed	kó<b>baffi ó<o>na	'finally break something' 'go (SG)'
l-grade	(none)[3]	pi<i>.sa	'(doesn't) see'

We assume that the phonological forms of each aspect are as shown in (6).

(6) Phonological forms

(a)	neutral	-Ø-
(b)	durative	-ń-
(c)	iterative	-hV́n- (or alternatively /hn/ with two moras)
(d)	terminative	-ˊyy-
(e)	resultative	-h-
(f)	delayed	-μ́-
(g)	l-grade	-μ-

[3] The l-grade is unique in that it does not contribute any identifiable semantic meaning. Instead, it is required that a verb also has the negative suffix -o or the sequential switch-reference markers -cha and -na. The fact that these suffixes require the l-grade and thus block any other aspect marking is noteworthy, but its motivation is unclear.

In the next subsection we will look at the interaction between these infixes and tense markers, which are suffixed to stems like those shown in (4) and (5). Broadwell (2006) analyzes three tense markers (though Katenkamp and Amber, 2025 argue that there are more).

(7) Choctaw tense suffixes (acc. Broadwell, 2006)

suffix	tense
-h	neutral/generic
-tok	recent past
-ttook	distant past

What is important to note here is that not all of the suffixes are same length- the generic tense *-h* becomes a coda on the final syllable of the stem, but *-tok* and *-ttook* add a syllable. The long vowel in (8.b) is the result of iambic lengthening, a process explained in Section 4.1.

(8) (a) pi.sah
pisa-h
see-TNS
'see'

(b) pi.saa.tok
pisa-tok
see-PST
'saw'

If we count the syllables from the right, we can see that the segmental material of the stem *pisa* 'see' is at different distances from the right edge of the word depending on which tense marker follows. For example, in (9.a), /sa/ occurs in the final syllable of the word, while in (9.b) it occurs in the penult.

(9) Counting syllables from the right edge

(a) pi_2 **sa**-h_1
(b) pi_3 **saa**$_2$ -tok_1

In the next subsection we will see how this difference in distance from the right edge can inform our understanding of the order of operations in phonological derivation.

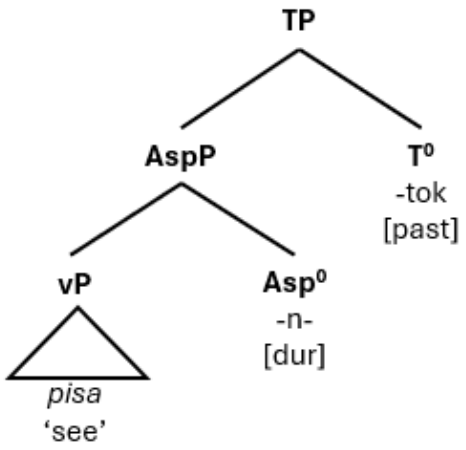
3.2. INFIXATION SITE AND TENSE SUFFIXES: In this section we focus on the durative aspect (the 'n-grade' in previous literature). As discussed previously, this infix surfaces after the penultimate vowel of the verb stem, regardless of the shape or length of the stem. If a phase were spelled out entirely at once, we would expect that the location of the aspectual infix relative to the phonological content of the stem to be different depending on which tense marker follows. However, this is not the case. Consider the forms in (10).

(10) (a) Neutral (b) Durative

(i)	pi.sah pisa-h see-TNS 'see'	(i)	pi**n**.sah pisa-n--h see-DUR--TNS 'look'
(ii)	pi.saa.tok pisa-tok see-PAST 'saw'	(ii)	pi**n**.sa.tok pisa-n--tok see-DUR--PAST 'looked'

The infix *-n-* appears in the same place in both forms- between /pi/ and /sa/- despite the fact that after the tense marker is concatenated, this location is a different distance from the right edge. If the entire phase was computed at once, the input to the phonology for (10.b.ii) would include both the infix *-n-* and the past tense marker *-tok*, i.e. /pisa+n+tok/. We would expect a form like **pisantok*, with the /n/ after the penultimate vowel /a/. But this is not what occurs.

(11) Syntactic structure



(12) Two different derivations

(a)	by phase (((pisa) -n-) -tok) /pisa+n+tok/ *[pi.sa**n.**tok]	(b)	by derivational step (((pisa) -n-) -tok) ((/pisa+n/) -tok) ([pinsa]) -tok) /pinsa+tok/ [pi**n.**sa.tok]

The consistency in infixation location relative to the root is unsurprising in a step-by-step analysis because the infixation occurs prior to the concatenation of any subsequent morphology that could move its landing site. Conversely, in an analysis with larger units of derivation, this landing site is inconsistent relative to the right edge of the word, which is much harder to explain.

Having established that phonological derivation must precede one morpheme at a time, we must answer the natural follow-up question: in what order do these derivational steps occur? Does the insertion of the infix *-n-* happen before the suffixation of *-tok* because it occurs first in the linear order of morphemes that we can see in (11) above? Or does the infixation occur first because it is at a lower syntactic terminal (Asp^0) than the suffix *-tok* (T^0)? There are two possible hypotheses, which are visualized in (13) below as alternative sequences of operations. Both begin with the complete construction of syntactic structure within a phase.

Then, in the 'linear order' hypothesis, linearization occurs all at once for the phase: the syntactic content of all the terminals is arranged in a linear sequence prior to any Vocabulary Insertion. Then, either from left-to-right or right-to-left, each root or feature bundle is replaced by a phonological string, concatenated to the existing stem, and subject to pure phonological processes before proceeding to the adjacent root or feature bundle in the sequence.

In the 'hierarchical order' hypothesis, everything occurs at individual syntactic terminals. So the structure of the phase initially remains intact, and then the three-step process of Spellout occurs at each terminal (moving up the tree). Vocabulary Insertion replaces roots or feature bundles with a phonological string according to Vocabulary Insertion rules, a 'local' process of linearization occurs, in which the string that was just inserted is concatenated to the larger stem, and then finally the form is subject to pure phonological processes.

(13) Two hypotheses

	hierarchical order	linear order
phase:	syntactic structure	syntactic structure full phase linearization
terminal:	vocabulary insertion 'local' linearization phonology	vocabulary insertion phonology

These hypotheses are named 'hierarchical' and 'linear' because they make different predictions about the order in which the phonological derivation of one morpheme will be sensitive to forms of other morphemes. In the linear order hypothesis, hierarchical structure has been lost and derivation proceeds according to linear order. But in the hierarchical order hypothesis, linearization hasn't occurred, so the sequence is determined by syntactic hierarchy.

To adjudicate between these two possibilities, we need a case study in which these two possible orders- hierarchical and linear- are different. Fortunately, the 'delayed' aspect (the g-grade) in Choctaw offers us exactly that.

4. Hierarchical versus linear order In this section we use g-grade forms of Choctaw verbs to demonstrate that the concatenation of morphemes proceeds up the morphosyntactic structure (hierarchical order), rather than left-to-right or right-to-left (linear order). The relevance of syntactic hierarchy tells us that linearization also occurs one morpheme at a time, rather than all at once before concatenation.

The case study here is the g-grade in Choctaw. This aspect marker is distinct in that it infixes from the left rather than right, meaning that it will linearly precede any morphemes that surface as suffixes, even if those morphemes originate lower in the syntactic tree. To make use of this unique ordering, we must first cover two other features of Choctaw morphophonology: transitivity marking in Choctaw, and a phonological process called iambic lengthening. The next subsection (4.1) explains these, and then Section 4.2. describes g-grade derivation and how the distribution of iambic lengthening between transitive and intransitive forms tells us that the hierarchical order hypothesis is correct.

4.1. TRANSITIVITY MARKING AND IAMBIC LENGTHENING: Most Choctaw verbs consist minimally of a root and one of two transitivity suffix. Many (but not all roots) can occur with both suffixes.[4] The suffixes have different shapes (14), yielding different syllabification for transitivity pairs derived from the same root (e.g. 15). In (15), the first syllable of the *in*transitive form is an open CV, while the first syllable of the transitive form is a closed CVC. The /h/ of the root is an onset in (15.b) and a coda in (15.c).

(14) Choctaw transitivity markers

(a)	-a	'intransitive'
(b)	-li	'transitive'[5]

(15) Choctaw transitivity pair

(a)	root:	tah
(b)	intransitive	/ta**.h**a/ 'end'
(c)	transitive	/ta**h.**li/ 'finish'

This interacts with the second subject of this section: iambic lengthening. Iambic lengthening is a phonological process in which even-numbered syllables in a sequence which non-final and underlyingly light are lengthened, creating a light-heavy alternation on the surface.

(16) Two different formalizations of iambic lengthening

$\sigma_{\mu}\ \sigma_{\mu} > \sigma_{\mu}\ \sigma_{\mu\mu}$

[4] Tyler (2020) documents different morphotactics in the Mississippi Choctaw speakers of today and argues for a three-way system featuring the suffixes *-a* 'intransitive', *-chi* 'transitive', and *-li*, which is underspecified. This appears to be a twentieth century innovation and is not shared by historical or Oklahoma varieties of Choctaw.

[5] The transitive forms in this paper do not usually have [li] on the surface because this suffix undergoes a variety of assimilation processes. What is constant, however, is that it has a /CV/ shape.

(C)VCV… > (C)VCV:…

There are many possibilities for why this process does not occur when the last two syllables of a word are light, but what is more important for us is that in non-final positions, iambic lengthening is blocked by a heavy syllable. Because many verb roots have the shape CVCVC and the two transitivity markers yield different syllabification, it is often the case that the intransitive form of a verb will exhibit iambic lengthening, but the transitive will not.

(17) Forms from the root *kobaf* 'break'

(a)	ko.**baa**.fa	(b)	ko.**baf**.fi
	kobaf-a		kobaf-li
	break-INTR		break-TRANS
	'break, become broken'		'break something'

In (17), the first two syllables of *kobaafa* are light syllables- /ko.ba/, making it a viable domain for iambic lengthening. Meanwhile the second syllable of *kobaffi* is heavy- /ko.baf/, so iambic lengthening does not apply. This is why we see a long vowel in *kobaafa* 'break' but not *kobaffi* 'break something'.

Aside from a few functional morphemes such as aa- 'LOC', or -oosh 'SR:SS', underlying long vowels are extremely rare in Choctaw. Almost all long vowels are underlyingly short and the result of either iambic lengthening or minimal word constraints.

4.2. THE G-GRADE: At the end of Section 3 we proposed that in order to tell whether concatenation occurs hierarchically or linearly, we need forms whose hierarchical and linear orderings differ. We cannot tell from the n-grade and tense marking examples from the case study in Section 3 because the orders align. Going step-by-step, the hierarchical ordering for these forms is stem, aspect, tense, which is the same as the linear ordering from left to right. This ambiguity exists for almost all aspect markers in Choctaw because most of them infix from the right. The one exception is the g-grade, which infixes from the left.

(18)	pinsatok		
	pisa	-n-	-tok
	see	-DUR-	-PST
	ROOT	Asp^0	T^0

The surface form of the g-grade varies between a long vowel or a geminate consonant. Additionally, the first syllable of the stem receives a pitch accent. We formalize the underlying form using the Vocabulary Insertion rule in (19).

(19) G-grade forms from Nicklas (1972) and Ulrich (1994:326)

	base	g-grade	
(a)	**ko.b**aa.fa	**kób.b**aa.fa	'to break'
(b)	**ta.l**ak.chi	**tál.l**ak.chi	'to be tied'
(c)	**o.**na	**óo.**na	'to arrive'

(20) VI rule for the g-grade

$Asp_{[delayed]}$ ⇔ μ́ / #μ_

Note that (19.a), *kóbbaafa* has a long vowel in its middle syllable. In (21) we see the intransitive and transitive forms of *kobaf* 'break' in the zero-grade (neutral aspect) and the g-grade. The distribution of length in the middle vowel is the same for both aspects: the intransitive has a long vowel, and the transitive has a short vowel (but a coda consonant).

(21) Forms of *kobaf* 'break'

	intransitive	transitive
zero-grade	kó.baa.fa 'break'	kó.baf.fi 'break (smt)'
g-grade	kób.baa.fa 'finally break'	kób.baf.fi 'finally break (smt)'

Linearly, the g-grade occurs first because it infixes from the left. Hierarchically, however, it occurs last.

If concatenation occurs hierarchically, we would expect the transitivity marker to attach to the root first, and for iambic lengthening to occur if the right domain occurs (as it does in *kobaafa* 'break'). Then the g-grade infixes, and cannot have any effect on iambic lengthening that has already occurred. If concatenation occurs linearly, the g-grade would infix to the root first, and because it makes the first syllable invariably heavy, would block iambic lengthening in the second syllable of the stem regardless of which transitive marker attaches after. These two derivational orders are shown below, with correct and incorrect forms noted as such.

(22) Transitive

	(a) Linear hypothesis:	(b) Hierarchical hypothesis:
Step 1:	/μ́ + ko.baf/ kób.baf	/ko.baf + li/ ko.baf.fi
Step 2:	[kób.baf] + li kób.b**a**f.fi	μ́ + ko.baf.fi kób.b**a**f.fi
	(correct form)	(correct form)

(23) Intransitive

	(a) Linear hypothesis:	(b) Hierarchical hypothesis:
Step 1:	/μ́ + ko.baf/ kób.b**a**f	/ko.baf + a/ ko.b**a.**fa [ko.b**aa.**fa]
Step 2:	kób.baf + a *kób.b**a**.fa	μ́ + ko.ba:.fa kób.b**aa**.fa
	(incorrect form)	(correct form)

We can see in (23.a) that moving linearly from left-to-right infixes the g-grade first, which blocks iambic lengthening. If this were the order of concatenation, we would expect to not see iambic lengthening in *any* of the g-grade forms, but this prediction is incorrect. Intransitive g-grade forms of verb roots with CVCVC shape (such as *kobaf*) consistently show lengthened vowels anyway.

The presence of lengthened vowels in these intransitive forms is unsurprising if we assume that the transitivity suffix attaches to the root first. Regardless of the aspect marker that will come later, /kobaf+a/ contains a viable domain for iambic lengthening, and so a long vowel will appear. Thus, we conclude that concatenation must occur hierarchically rather than linearly, and that linearization does not happen all at once, but as a step within each morpheme-by-morpheme derivation.

5. Conclusion: We can observe from Choctaw aspectual infixes two crucial facts about the order of operations in phonological derivation. Firstly, that Spellout occurs one morpheme at a time, rather than at larger constituent boundaries. Secondly, the order of concatenation is determined by syntactic structure and is irrespective of linear order. This means that there is no dedicated step in the derivation in which linearization occurs. Instead, a linear string is built up with the output of Vocabulary Insertion one syntactic terminal at a time, i.e. linearization is distributed between steps of Vocabulary Insertion.

Overall, we have shown that the order of operations in phonological derivation is as follows. When a phase of morphosyntactic structure is complete, Vocabulary Insertion takes place at each terminal in the structure, starting from the bottom and proceeding upward. Each step of Vocabulary Insertion (i.e. what occurs at the syntactic terminal) is that abstract roots or features are replaced with a phonological string according to the relevant Vocabulary Insertion Rules. Then this phonological material is concatenated to the existing primary phonological string (if there is one), and phonological processes, whether rule- or constraint- based, apply to generate the string that will be handed up to the next terminal, where the process repeats cyclically until the syntactic terminals are exhausted.

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